The relative contribution of synoptic types to rainfall over the Cape south coast region

Christien J Engelbrecht,[1,2] Willem A Landman[2,3] and Francois A Engelbrecht[3]

[1]Agricultural Research Council, Institute for Soil, Climate and Water, Pretoria, South Africa

[2]Department of Geography, Geo-informatics and Meteorology, University of Pretoria, Pretoria, South Africa

[3]Council for Scientific and Industrial Research, Climate Studies, Modelling and Environmental Health, Pretoria, South Africa

Abstract

A synoptic decomposition of rainfall over the Cape south coast region for the period 1979-2011 is presented. This decomposition is achieved by considering the average daily low-level circulation to develop a synoptic climatology, using a Self Organising Map (SOM) technique. Daily area-average rainfall derived from weather station rainfall data is related to the identified synoptic types. It is shown that ridging high pressure systems are responsible most of the annual rainfall (41%) over the Cape south coast region, followed by tropical-temperature troughs (24%), cut-off lows (COLs) (13%), frontal troughs (12%), continental trough – ocean ridge combinations (8%) and weak synoptic flow (2%).

Key words: Cape south coast, synoptic climatology, ridging high-pressure systems, cut-off lows

INTRODUCTION

The Cape south coast region of South Africa receives rainfall all-year round with slight peaks observed during autumn and spring (Weldon and Reason 2013). Rain-producing weather systems of the region include cold fronts, west-wind troughs, cut-off lows (COLs), ridging high pressure systems and tropical-temperature troughs (Hart et al., 2012, Weldon and Reason 2013). The relative contributions of these different weather systems to rainfall over the Cape south coast region have not been quantified to date. Of particular interest in this composition, is the contribution of COL induced rainfall relative to rainfall associated with other weather systems - with special emphasis on ridging high pressure systems.

DATA AND METHOD

Sixteen weather stations from the South African Weather Service (SAWS) bounded by 21° E and 27° E and representative of the coast, adjacent interior and deep interior extending to 32° S, are chosen on the basis of their availability and completeness of the daily rainfall data for the period 1979-2011. Daily area average rainfall for the coast (stations 1 to 9), near-coast (stations 10 to 13) and interior (stations 14 to 16) is calculated from the weather station data (Fig. 1). The coastal and adjacent interior regions are defined as the "Cape south coast" region. The deeper interior is included in this analysis to provide some context of the behavior of rain producing weather systems over the all-year rainfall region of the Cape south coast, to that of the neighboring summer rainfall region over the interior.

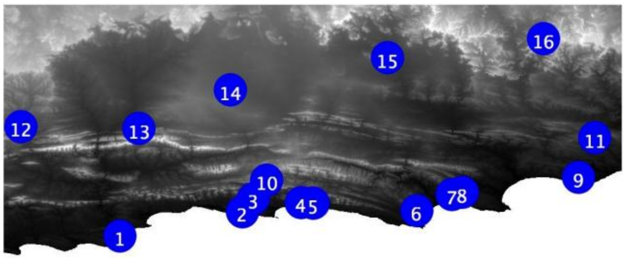

Fig. 1. Location of the weather stations representative of the coast (stations 1 to 9), adjacent interior (stations 10 to 13) and the interior (stations 14 to 16).

Daily mean sea-level pressure (SLP) with a horizontal resolution of 2.5° x 2.5° from the National Centers for Environmental Prediction (NCEP) reanalysis data (Kalnay et al., 1996) for the period 1 January 1979 to 31 December 2011 is utilized for the classification of the synoptic circulation. The self-organizing map (SOM) technique (Kohonen 2001) is used to objectively classify the weather patterns that influence the Cape south coast region. Anomaly SLP is used to develop the SOM, as the atmospheric circulation depends on SLP gradients and not the actual magnitudes of the SLP (Schuenemann et al., 2009). Daily SLP anomalies at each grid point are calculated by subtracting the daily domain average SLP from the grid point value. The analysis is performed for the domain 45° S to 32.5˚ S and 10° E to 40˚ E. The selected region allows for capturing the progression of high pressure systems and troughs, advancing from west to east, to the south of the Cape south coast. The northern boundary of the SOM region is selected to extend only to 32.5˚ S in order to avoid the SOM being dominated by the prevailing wintertime high pressure systems over the interior. Furthermore, SLP is used as variable to develop the SOM, as the low-level circulation over the oceans bordering the subcontinent is crucial in inducing rainfall over the Cape south coast. It may be noted that all the known rainfall producing synoptic patterns are captured within the SOM. For the purpose of this study, it is appropriate to apply a relatively large SOM (7x5) to avoid over generalization of the SOM patterns. To relate rainfall to the main weather systems, the daily area average rainfall for the coast, near-coast as well as the interior are individually mapped to the SOM. For each day in the time-series of 12053 days, the circulation pattern is associated with one of the SOM's synoptic types. The corresponding daily rainfall is subsequently associated with the relevant synoptic type.

To explore in further detail the role of COLs in inducing rainfall over the Cape south coast, NCEP reanalysis data are utilized for the purpose of identifying and tracking COLs for the period 1979-2011. A COL is defined as a local minimum in the geopotential height at the 500 hPa pressure level, accompanied by a cold-core, similar to the criteria used by Favre et al. (2012). The tracking is performed using a daily time-step, using a modified version of the objective, automated tracking algorithm developed by Engelbrecht et al. (2013), Only COLs existing for at least two days are considered in this study. Geopotential minima are identified by considering each grid point in the domain bounded by 40˚ S – 20˚ S and 10˚ E – 40˚ E, through comparison to the geopotential values of the eight surrounding grid points. Potential COL tracks are constructed by identifying the nearest geopotential minima of time step *t+1* that occurs within a 1000 km from the geopotential minima at time step *t*. This distance criteria limits COLs to move faster than 42 km/h (following Favre et al., 2012). The tracking procedure is developed in such a manner that geopotential minimums can only be employed in one track (one potential COL event). All these potential COL events are then subjected to a cold-core test. The approach utilized by Favre et al. (2012) is applied in this study. For each of the tracks, a temperature minimum needs to be located within 600 km from the geopotential height minimums that form part of a track. To accommodate hybrid systems (e.g. systems that only exhibit a cold-core structure during a part of their life cycle), this temperature minimum distance criteria is adjusted in this study – a cold-core needs to be present more than half of the time-steps for a track to be classified as a COL track. From the COL dataset constructed in this way for the period 1979-2011, all the COLs that occurred within 700 km from the centroid of the study region is considered to be potentially responsible for rainfall over the study region. COLs that are associated with rainfall at one or more stations are defined as rainfall producing COLs.

DISCUSSION

The various configurations of the main synoptic patterns are captured within the 7x5 SOM. An attribute of SOMs is the ability to group adjacent nodes in the SOM space together for analysis purposes of the main synoptic types, while the variation found within a main synoptic type is represented by the nodes that are grouped together. The 35 nodes are grouped into 6 main synoptic types. The main synoptic types identified by the SOM that is relevant to the Cape south coast region are troughs southwest of the subcontinent, troughs southeast of the subcontinent, ridging high pressure systems from the southwest, high pressure systems located east of the subcontinent, tropical-temperate troughs and weak synoptic flow.

COLs are not exclusively identified by the SOM, as COLs occur too infrequent compared to the other circulation patterns. COLs are therefore independently identified. During 1979-2011, 179 COL events (286 COL days) were associated with rainfall over the study region. COL induced rainfall over the study region is mostly associated with COLs located over the southwestern interior (Fig. 2).

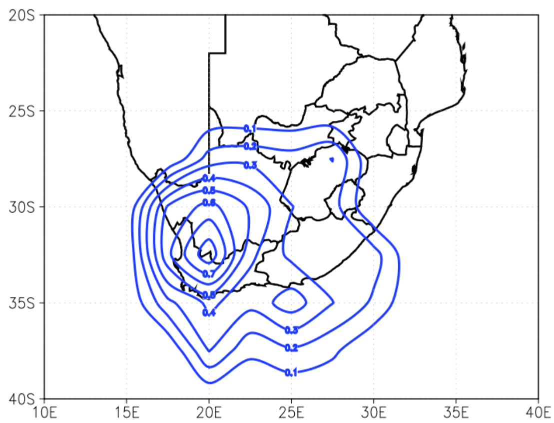

Fig. 2. Mean annual COL frequency (COL days per grid point) of COLs associated with rainfall over the study region.

COLs contribute in general 10-15% to the annual rainfall over the study region. The surface circulation that accompanies a COL, can be either a high pressure system southwest or southeast of the subcontinent, or a tropical-temperate trough (Fig. 3).

The contribution of COLs to the annual rainfall over the study region (in the order of 10 to 15 %), is much less than the contribution by ridging highs (see Figure 4). However, on average only 5 COLs (179 COL events during 1979-2011) contribute to rainfall over the Cape south coast region while ridging highs occur more frequently.

High pressure systems ridging from the southwest, is the main weather system contributing to rainfall along the Cape south coast (41%, Fig. 4 a, bar 3) and southwards of the Cape folded mountains at 33° S (30%, Fig. 4 b, bar 3), followed by tropical-temperate troughs (Fig. 4 a and b, bar 5). The neighboring interior (Fig. 4 c), a summer rainfall region, receives most of its rainfall from tropical-temperature troughs (37%, bar 5).

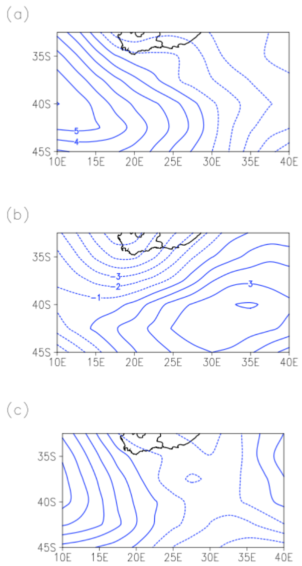

Fig. 3. Surface circulation types that accompany COLs associated with rainfall over the Cape south coast region: (a) ridging high pressure system from the southwest, (b) high pressure system southeast of the subcontinent and (c) tropical-temperate trough.

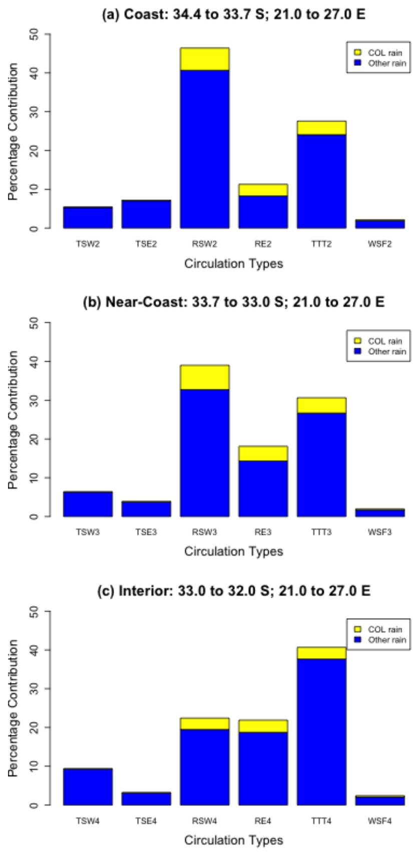

Fig. 4. Mean annual contribution of troughs southwest of the subcontinent (bar 1), troughs southeast of the subcontinent (bar 2), high pressure systems southwest of the subcontinent (bar 3), high pressure systems southeast of the subcontinent (bar 4), tropical-temperature troughs (bar 5) and weak synoptic flow (bar 6) to the annual rainfall over (a) the coast, (b) near-coast and (c) interior extending to 32° S. The contribution by COLs to rainfall is indicated in yellow.

CONCLUSION

The importance of ridging high pressure systems to rainfall over the Cape south coast region is illustrated by its contribution of 41% to the total annual rainfall, followed by tropical temperature troughs with 24% and COLs with 13%. This result has important implications for seasonal forecasting and the projection of future climate change over the region (as it suggests that particular emphasis should be placed on the skilful prediction/projection of changes in the frequency of occurrence of these synoptic types). It also points to the importance of models to simulate tracks and frequency of occurrence of ridging highs, as well as interactions of associated low-level flow with the topography realistically, for predictions and projections to be reliable.

REFERENCES

Engelbrecht CJ, Engelbrecht FA, Dyson L. 2013. High-resolution model-projected changes in mid-tropospheric closed-lows and extreme rainfall events over southern Africa. International Journal of Climatology 33(1): 173-187. DOI: 10.1002/joc.3420.

Favre A, Hewitson B, Tadross M, Lennard C, Cerezo-Mota R. 2012. Relationships between cut-off lows and the semi-annual and southern oscillations. Climate Dynamics 38(7): 1473-1487. DOI: 10.1007/s00382-011-1030-4.

Hart NCG, Reason CJC, Fauchereau N. 2012. Cloud bands over southern Africa: seasonality, contribution to rainfall variability and modulation by the MJO. Climate Dynamics. DOI: 10.1007/s00382-012-1589-4.

Kohonen T. 2001: Self-Organizing Maps. 3rd ed. Springer, 501 pp.

Schuenemann KC, Cassano JJ and Finnis J. 2009. Synoptic forcing of precipitation over Greenland: Climatology for 1961-99. Journal of Hydrometeorology 10. 60-78.

Weldon D and Reason CJC. 2013. Variability of rainfall characteristics over the South coast region of South Africa. Theoretical and Applied Climatology. DOI: 10.1007/s00704-013-0882-4.